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ABSTRACT

This investigation was undertaken in order to establish the status of scientific literacy among three groups of secondary school students in four Brisbane, Australia high schools, and to reduce the apparent reticence of science teachers to evaluate students' achievement in the various dimensions of scientific literacy by demonstrating appropriate evaluation techniques. Assessment of students' attainment of scientific literacy, as defined by Showalter (1974), would require a battery of seven tests, each specifically developed to span one of the dimensions of scientific literacy. Baseline data presented here indicate that student achievement in science knowledge, problem solving, values underlying science, interrelationship of science and society, and interests in science, was low. While it is acknowledged that the low mean scores to some extent reflect the procedures adopted in constructing the test instruments, comparative data for year 10 (N=567) and year 12 (N=273) students show that differences in scores on the various test scales occur according to year, whether or not science was studied. (DS)

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SCIENTIFIC LITERACY OF HIGH SCHOOL STUDENTS

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SCIENTIFIC LITERACY OF HIGH SCHOOL STUDENTS

Introduction

Increasingly in our society the findings of science and the products of technology mould our environment, influence our thinking, and determine our destiny. In response, science educators have made the raising of the level of scientific literacy in the general populace a major aim of science curricula and materials developed since 1960.

The concept of scientific literacy has been defined in various ways (Pella, O'Hearn, and Gale, 1966; Thomson and Voelker, 1970; Rubba and Andersen, 1978). A useful approach, that of identifying characteristics of a scientifically literate person, was taken by Showalter (1974) in describing seven dimensions of scientific literacy:

I. The scientifically literate person understands the nature of scientific knowledge.

II. The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe.

III. The scientifically literate person uses processes of science in solving problems, making decisions, and furthering his own understanding of the universe.

IV. The scientifically literate person interacts with the various aspects of his universe in a way that is consistent with the values that underlie science.

V. The scientifically literate person understands and appreciates the joint enterprise of science and technology and the interrelationships of these with each other and with other aspects of society.

VI. The scientifically literate person has developed a richer, more satisfying, and more exciting view of the universe as a result of his science education and continues to extend this education throughout his life.

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VII. The scientifically literate person has developed numerous manipulative skills associated with science and technology. (p.2)

Even when the term 'scientific literacy' is not specifically used in a particular science syllabus it is often clear from the statement of aims that it has been a major concern of the syllabus authors. For example, a cursory examination of the cognitive, manipulative, and affective aims of the Syllabus in Science for Queensland Secondary Schools (Board of Secondary Schools Studies, 1977) shows clearly that, if all were afforded equal importance and satisfactory levels of competence were achieved by students, then those students could be aptly described in Showalter's terms as scientifically literate individuals.

Despite the recognition among science educators of its importance there has been no concerted attempt to ascertain how effective modern science courses have been in developing scientific literacy. Lack of appropriate tests, and a social climate which fosters scepticism concerning evaluations other than numerical measures of academic excellence, have been the major reasons for this evaluation gap. Consequently the true situation regarding the level of scientific literacy among secondary school students remains a matter for conjecture.

This exploratory investigation was undertaken in order to

(i) establish the status of scientific literacy among three groups of secondary school students in four Brisbane high schools, and

(ii) reduce the apparent reticence of science teachers to evaluate students' achievement in the various dimensions of scientific literacy by demonstrating appropriate evaluation techniques.

For the purpose of the study, the status of scientific literacy was defined as the set of scores obtained by students on the three tests employed. As described in a later section these tests together spanned five of the seven dimensions of scientific literacy defined by Showalter.

Research Questions

The three research questions under consideration in the study were:

(1) What is the status of scientific literacy among year 10 students whose curriculum includes science as a subject?

(2) What is the status of scientific literacy among year 12 students whose curriculum includes at least one science subject?

(3) What is the status of scientific literacy among year 12 students whose curriculum does not include any science subject?

Sample

The sample consisted of 567 year 10 students and 273 year 12 students in four comprehensive state high schools in Brisbane. All students were enrolled in at least one science course except for 39 year 12 students who had dropped science before commencing year 11. The tests were administered mid-year at about the time of the first semester examinations. Every student present on the test day was included in the sample.

Selection of the schools was not intended to produce a random sample of the student population in Queensland high schools. The four schools which were chosen are located in middle class suburbs and are quite typical of state high schools in Brisbane. The smallest of the three student groups under examination was the year 12 non-science students, and four schools were included so that this group would comprise at least 50 students. In fact only 39 of these students were present on the test day.

Instruments

Assessment of students' attainment of scientific literacy as defined by Showalter (1974) would require a battery of seven tests, each specifically developed to span one of the dimensions of scientific literacy. Whereas the investigators undertook the development of one such test it was their intention to use published tests which could be conceptually linked with Showalter's dimensions wherever possible. This pragmatic approach resulted in the operationalisation of the term 'scientific literacy' in terms of achievement of students on the particular battery of tests selected rather than strictly along the lines of Showalter's (1974) definition.

Of the seven dimensions of scientific literacy numbers I and VII were not spanned by the tests employed. The others were, to some extent as summarized in Table I.

Table I

Test Instruments for Measuring Various Dimensions of Scientific Literacy

DIMENSION OF SCIENTIFIC LITERACY	SCALE NAME	APPLICATION
I. Nature of scientific knowledge	Nature of Science Knowledge Scale, NSKS	Not used - questionable validity
II. Applied science knowledge	Test of Basic Science Knowledge, TBSK	Specifically designed to measure this dimension
III. Science processes in problem solving	Science Process Inventory, SPI	Not used - questionable validity
	Test of Enquiry Skills, TOES	TOES scales, 7, 8, 9
IV. Values underlying science	Attitude Toward Scientific Inquiry, ATTI	One scale of TOSRA
	Adoption of Scientific Attitudes, ATTA	One scale of TOSRA
V. Interrelationships of science, technology and society	Social Implications of Science, ATTS	One scale of TOSRA
	Normality of Scientists, ATTN	One scale of TOSRA
VI. General and abiding interest in science	Enjoyment of Science Lessons, ATTE	One scale of TOSRA
	Leisure Interest in Science, ATTL	One scale of TOSRA
	Career Interest in Science, ATTC	One scale of TOSRA
VII. Associated manipulative skills	-	Practical test not considered appropriate for present study

Nature of Scientific Knowledge Scale (NSKS)

In the early stages of the investigation the Nature of Scientific Knowledge Scale, NSKS, (Rubba and Andersen, 1978) seemed an ideal choice. It was specifically developed to assess secondary school students' understanding of the nature of scientific knowledge which is the first of Showalter's dimensions of scientific knowledge. However, the NSKS had not been used with Australian students so a pilot study was undertaken. During the pilot study it became evident to the investigators that the validity of the NSKS was questionable. Many of the year 10 students involved commented on the fact that the test kept asking the same thing in different words and that it was too obvious in respect of the answer that they thought was expected of them. When questioned further, they admitted to having consciously adjusted some of their responses so as to appear consistent.

Reluctantly it was decided not to use the NSKS. Thus, assessment of the first dimension of scientific literacy was not attempted. Table A1 in the Appendix includes the results of the pilot study involving the NSKS.

Test of Basic Science Knowledge (TBSK)

The Test of Basic Science Knowledge, TBSK, was developed by the investigators specifically to measure students' achievement along the second dimension of scientific literacy. Showalter (1974) elaborated this dimension by listing 29 key concepts of science. Eight experienced science educators were asked to rate each concept on a five point scale in terms of its importance in development of basic science knowledge for year 10 students. Of the 29 key concepts, 11 received strong or moderately strong support and were selected for inclusion in the test (see below). An examination was made of the science syllabus used in Queensland schools (Board of Secondary Schools Studies, 1977) and a selection made of material appropriate to each of Showalter's key concepts.

The same eight science educators indicated their individual judgments concerning the proportion of questions in TBSK which should be written at the various levels of cognitive achievement elucidated by Bloom (1956). When the three highest levels were combined, the resulting consensus was 25% knowledge questions, 29% comprehension, 25% application, and 21% higher level.

Three approximately equivalent multiple choice type versions of TBSK having about 44 questions each, were prepared according to the above specifications. These were trialled with year 10 students in selected metropolitan and country high schools in south-east Queensland. Each test was attempted by approximately 240 students.

Following item analysis and rejection of those items with unacceptable difficulty level ($p > 0.8$ or $p < 0.2$) or discrimination index (< 0.1) the final version of TBSK was constructed. To check the face validity of the test it was sent to ten science teachers who were asked to classify each question according to the syllabus area being tested. Their replies, summarized in Table II, indicated that questions were equally divided between the physical sciences and the natural sciences which is a distribution consistent with the syllabus. The teachers also rated each question according to its level of cognitive demand. There was a majority agreement among the teachers for 31 of the 50 questions on TBSK, and opinions about the remaining 19 differed considerably. For the test as a whole the classification of test items by the teachers was 26% knowledge level questions, 36% comprehension, 32% application, and 6% higher level.

Table II

Distribution of Questions on the TBSK Across Eleven Key Concepts of Science and Ten Teachers' Judgment of Syllabus Areas Being Tested

KEY CONCEPT (Showalter, 1974)	NUMBER OF QUESTIONS	SYLLABUS AREA TESTED			
		Biology	Chemistry	Earth. Sc.	Physics
Cause-effect	7	X (5)		X (1)	X (1)
Change	3		X (1)	X (1)	X (1)
Cycle	7	X (3)		X (4)	
Force	4		X (1)	X (1)	X (2)
Energy-matter	4		X (2)		X (2)
Fundamental activities	4		X (4)		
Interaction	5		X (4)		X (1)
Model	3		X (3)		
Organism	5	X (5)			
Quantification	4		X (2)		X (2)
Time-space	4			X (4)	

* Numbers in brackets are the number of questions in each syllabus area for each key concept

The final version of TBSK used in the study had a reliability co-efficient (KR-20) of 0.78 for year 10 and 0.86 for year 12 students.

Science Process Inventory (SPI)

The Welch Science Process Inventory, SPI, (Welch and Pella, 1968) is a well known instrument which purports to assess the knowledge of the processes of science possessed by secondary school students. Although 'knowledge of the processes of science' is not equivalent to 'uses the processes of science' as outlined in the third dimension of scientific literacy, it is likely that the two are highly correlated. Therefore it was the investigators' intention to use the SPI to assess students' achievement in this area.

As was the case with the NSKS a pilot study was undertaken to gather information about the SPI with Australian secondary students. Table A1 in the Appendix summarises the results. Once again, the validity of the instrument was brought into question during the pilot study. Teachers consulted were concerned with the high reading level and large number of test items. It also became clear that a sizable proportion of year 10 students attempting the SPI could not adequately read it or maintain the level of interest required to complete it. Consequently it was decided not to proceed with the use of the SPI in the main study.

Test of Enquiry Skills (TOES)

Fraser's (1980) Test of Enquiry Skills comprises nine separate scales. Three critical thinking in science skills are measured by the last three of these scales. They are comprehension of science reading material, design of experimental procedures in science, and the ability to draw valid conclusions and generalizations from data. These skills are essential and major components of achievement in the third of Showalter's dimensions of scientific literacy. Thus the combined scales 7, 8, and 9 of TOES were employed.

No pilot study of TOES was carried out as the instrument was developed and validated in Australia. However, neither Fraser's nor the present sample was randomly chosen so some variation from the published statistical data for TOES (Fraser, 1980, p.12) was to be expected. Results to be reported below show considerable variation from Fraser's figures; the means on each scale being lower and the reliability co-efficients higher than previously reported. In addition data are reported for year 12 students completing scales 7, 8, and 9 of TOES.

Test of Science Related Attitudes (TOSRA)

All of the seven scales which comprise the Test of Science Related Attitudes, TOSRA (Fraser, 1978), are conceptually related to Showalter's dimensions of scientific literacy. Each of the fourth, fifth, and sixth dimensions is partially spanned by at least two of the TOSRA scales, as shown in Table I. Therefore, the entire TOSRA was employed.

As was the case for TOES, no pilot study of TOSRA was carried out. Results to be reported below are very similar to those obtained by Fraser (1978) for year 10 students. In addition data are reported for year 12 students completing TOSRA.

Test Battery

In summary, the three test instruments which comprised the test battery were TBSK, TOSRA, and scales 7, 8, and 9 of TOES. These were administered in two sessions each of one hour duration. In one session students completed TBSK, and in the other both TOSRA and TOES.

Results

The results obtained by all students on the three test instruments are shown by year in Table III.

Table III

Mean Score, Standard Deviation, Reliability, and Standard Error of Measurement of Each Scale

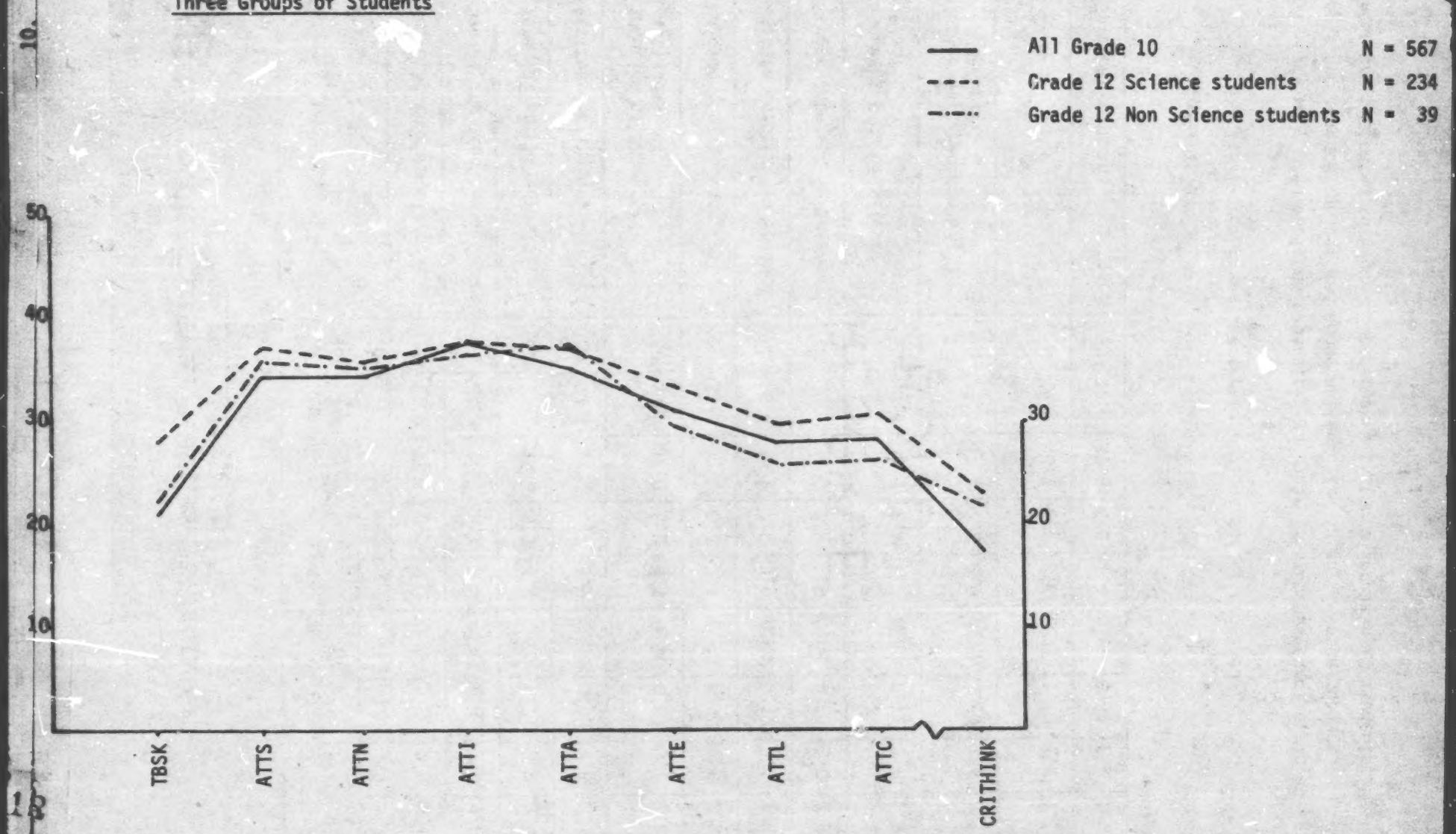
SCALE	MAX. SCORE	Mean in Year		S.D. in Year		[a]Reliability in Year		Standard Error of Means	
		10	12	10	12	10	12	10	12
Basic Science Knowledge	50	21.2	27.1	6.9	8.2	0.78	0.86	2.6	3.1
Social Implications of Science	50	34.3	37.0	6.7	5.9	0.81	0.81	2.9	2.6
Normality of Scientists	50	34.2	35.2	5.3	4.4	0.69	0.71	3.0	2.4
Attitude to Inquiry	50	37.4	37.2	6.6	5.9	0.82	0.83	2.8	2.4
Adoption of Scientific Attitudes	50	34.9	37.0	5.2	4.9	0.64	0.67	3.1	2.8
Enjoyment of Science Lessons	50	31.3	32.9	8.4	7.4	0.90	0.90	2.6	2.3
Leisure Interest in Science	50	28.0	29.2	7.8	7.9	0.84	0.87	3.1	2.8
Career Interest in Science	50	28.1	30.0	7.7	7.9	0.85	0.88	3.0	2.8
Comprehension of Science Reading	10	6.8	8.6	2.6	1.7	0.80	0.72	1.2	0.9
Design of Experimental Procedures	10	5.7	7.4	2.6	2.0	0.73	0.60	1.4	1.2
Conclusions and Generalisations	9	4.9	6.9	2.6	2.0	0.77	0.70	1.2	1.1
[b]Critical Thinking in Science	29	17.4	23.0	6.8	4.8	0.89	0.84	2.2	1.9

[a] Co-efficient alpha

[b] This scale comprises the three previous scales combined

Data were also analysed separately for year 12 students enrolled in at least one science subject and those not enrolled in any science subject. These are presented in Figure 1 together with those for year 10 students.

Figure 1 Scientific Literacy Test Score Profiles for Three Groups of Students



Note that the first eight scales have a maximum possible score of 50. The last scale shown (combined TOES scales) has a maximum score of 29. A score of 12.5 and 6 is possible by chance alone on the first and last scales respectively. The other seven (TOSRA) scales have a minimum score of 10 and a neutral score of 30.

Pearson correlation co-efficients between scores on all scales were computed by year and school as indicies of discriminant validity (Fraser, 1978). Intercorrelations between TBSK scores and other scales in the battery were generally low, with a range from 0.14 to 0.64 and mean of 0.39 for the largest school. Similarly, TOSRA scale intercorrelations ranged from 0.11 to 0.79 with a mean of 0.43. TOES scale intercorrelations ranged from 0.52 to 0.73 with a mean of 0.60. These results are consistent with those published by Fraser (1978, 1980) although the TOES intercorrelations are considerably higher than he reported.

Furthermore, intercorrelations between TOSRA and combined TOES scales were also generally low, ranging from 0.16 to 0.51 with a mean of 0.35. Since all the intercorrelations were smaller than the square root of the product of the corresponding scale reliabilities (Fraser, 1978), the seven TOSRA scales and combined TOES scales may be considered to be measuring achievement in different areas.

Nevertheless, intercorrelations between scales tended to be statistically significant. An unexpected result was that the pattern of intercorrelations varied greatly between years and schools. This is illustrated in Figure 2 where correlation matricies for each school are displayed. In each case the upper half-matrix refers to year 10 students and the lower half to year 12. Only the locations of correlation co-efficients which failed to reach statistical significance at the 0.05 level are shown in Figure 2.

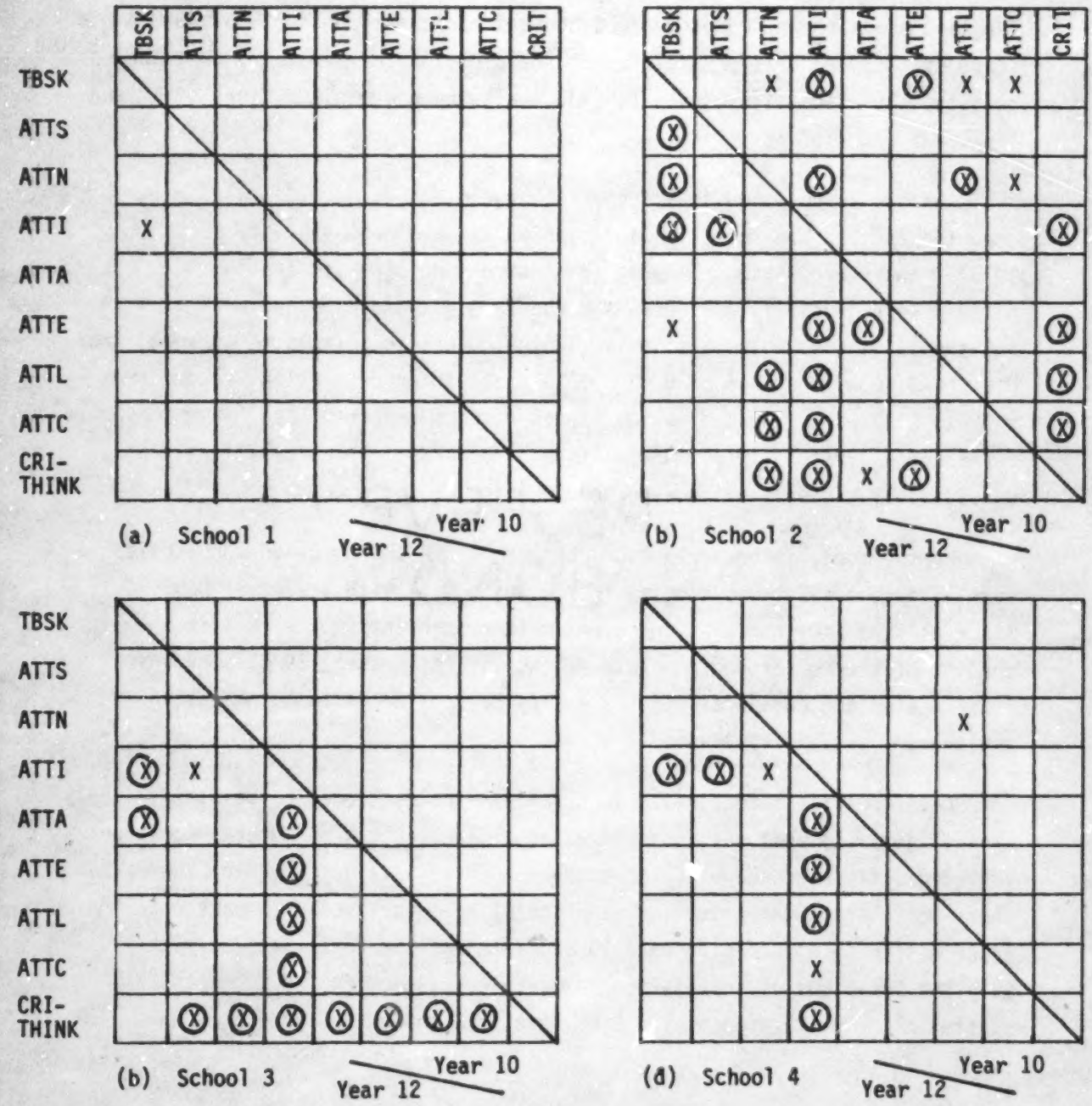


Figure 2. Locations of interscale correlation co-efficients which are NOT significant at the 0.05 level, shown thus: X.
Correlation co-efficients which are NOT significant at the 0.10 level are shown thus: (X).

Discussion

The status of scientific literacy of students in years 10 and 12 determined by the present study is cause for concern among Queensland science educators. Baseline data presented here indicate that student achievement in the five dimensions of scientific literacy studied is low. While it must be acknowledged that the low mean scores to some extent reflect the procedures adopted in constructing the test instruments, comparative data for year 10 and year 12 students are far from encouraging. Examination of Figure 1 shows that differences in scores on the various test scales occur according to year and whether or not science was studied. These differences are in the direction anticipated, but they are surprisingly and disappointingly small.

Science Knowledge (Dimension II)

For year 10 students, the mean score on the specially constructed test of basic science knowledge was only 21/50 and the maximum score was 40/50. The mean score for year 12 students was 27/50 and the maximum 46/50. When it is remembered that many of the less able students leave school after year 10 the difference of only 7 in the mean score between years 10 and 12 suggests that the extra two years studying science does not result in very much better knowledge of basic scientific facts and principles.

In the development of TBSK only eleven of Showalter's (1974) key concepts were considered. These were the concepts which were most strongly

supported by a group of Queensland science educators as important in the development of basic science knowledge for year 10 students. Furthermore, adequate coverage of the science syllabus was attested by ten science teachers, none of whom registered any misgivings about the difficulty of the test. It is therefore somewhat surprising that no year 10 student scored more than 40/50, and no year 12 student more than 46/50 on TBSK. Student attainment in this dimension of scientific literacy does not appear to be as high as science educators would desire.

Problem Solving (Dimension III)

The combined scales 7, 8, and 9 of TOES were used as a measure of student achievement in the third dimension of scientific literacy. Mean scores were 17.4 for year 10 students, 21.9 for year 12 non-science, and 23.2 for year 12 science students out of a possible score of 29. It is interesting that, although the number of year 12 non-science students was small, their mean score was closer to that of their science studying peers than to the year 10 students' mean score. Perhaps this result is indicative of the importance of maturation in the development of critical thinking in science skills. Further investigation in this area is necessary before the full significance of the data presented in this paper can be realized.

Values Underlying Science (Dimension IV)

Two scales of TOSRA, attitude toward scientific inquiry (ATTI) and adoption of scientific attitudes (ATTA), were taken as measures of attainment in this dimension of scientific literacy. Results presented in Figure 1 indicate that mean scores on both scales were between 35 and 38 for the three groups of students involved in the study. Since a score of 30 on each TOSRA scale is a 'neutral' score with respect to that particular attitude the results obtained are somewhat encouraging for Queensland science teachers. However, the fact that mean scores for year 10 and year 12 students on these scales are virtually equivalent, notwithstanding the more selective nature of the year 12 population, is disappointing.

Interrelationships of Science and Society (Dimension V)

The two TOSRA scales used as indicators of attainment in this dimension were social implications of science (ATTS) and normality of scientists (ATTN). Results presented in Figure 1 are similar to those obtained for Dimension IV, namely mean scores a little higher than the neutral score on each attitude

scale and almost equivalent for all three groups of students studied. The syllabus in science for Queensland schools includes the topic 'Science Applied to Social and Industrial Problems'. It is the present investigators' belief that little attention is given to this topic by teachers and the results of the study indicate that there is considerable scope for improvement of students' mean scores on the two scales used. Further investigation in this area may prove to be rewarding.

Interest in Science (Dimension VI)

Enjoyment of science lessons (ATTE), leisure interest in science (ATTL) and career interest in science (ATTC) were the three TOSRA scales used as indicators of student attainment in this dimension of scientific literacy. Overall the mean scores were neutral to slightly negative, as shown in Figure 1. Year 12 science students scored higher than year 10 students on all three scales, while year 12 non-science students had the lowest mean scores on all three scales. These results are spread in the manner which would be expected when consideration is given to the fact that the year 12 students not studying science would have considered their interests and career plans before deciding on the subjects to study in senior high school. It is, however, surprising and disappointing to discover that even students who elect to study science subjects in the senior high school do not nave strong leisure or career interests in science when compared with year 10 students.

Interschool Differences

The question of why different patterns of intercorrelations between scales were obtained for different schools and years is not answered in this study. One possibility is that the lower correlations in year 12 result from the restricted ability range of students proceeding to senior high school. Lower correlation co-efficients would be anticipated from a more homogeneous group of students, but the effect is virtually absent in school 1 and confined to particular sections of the matricies for the other schools.

Another possibility is that differences in the science programs and teaching methods employed in the different schools is responsible. The tendency for scores on the attitude to inquiry (ATTI) scale not to be

significantly correlated with scores on other scales for year 12 students may be related to different styles of teaching science in the senior high school.

School 2 is different from the others because of its larger number of non-significant intercorrelations and the fact that the patterns are similar for both years. Further investigation is necessary before a satisfactory explanation of these differences can be made.

Individual Student Profiles

When it was shown that many of the intercorrelations between scales were statistically significant but low, it was suspected that the test result profiles of individual students could vary widely. Accordingly, eight students were chosen from school 1, where virtually all of the intercorrelations between scales were statistically significant at the 0.05 level, and profiles for each student were constructed. These profiles are presented, with the standard errors of measurement, in Figures 3 and 4 (see the following two pages).

The eight students were specifically chosen in order to demonstrate what is considered to be a major weakness in the evaluation scheme used in many schools, where science achievement is measured solely by a test such as TBSK. Even a cursory examination of the results for year 10 students A, B, C, and D if Figure 3 shows considerable differences between students. While A scored slightly higher than B on TBSK, B's profile is significantly higher than A's on ATTA and ATTC but significantly lower on CRITHINK. (Similar results are shown for four year 12 students in Figure 4). Even though the difference between A and B on TBSK is not significant, A would be the student awarded the higher grade and no indication of B's higher scores on other scales would be given in the reports issued by many schools. A similar situation exists for the other students represented in Figures 3 and 4. Many other students could have been selected from each school involved in the study in order to illustrate the considerable variation in attainment across the various dimensions of scientific literacy shown by students with the same score on TBSK.

Figure 3 Scientific Literacy Test Score Profiles

Four Grade 10 Students

Page 17.

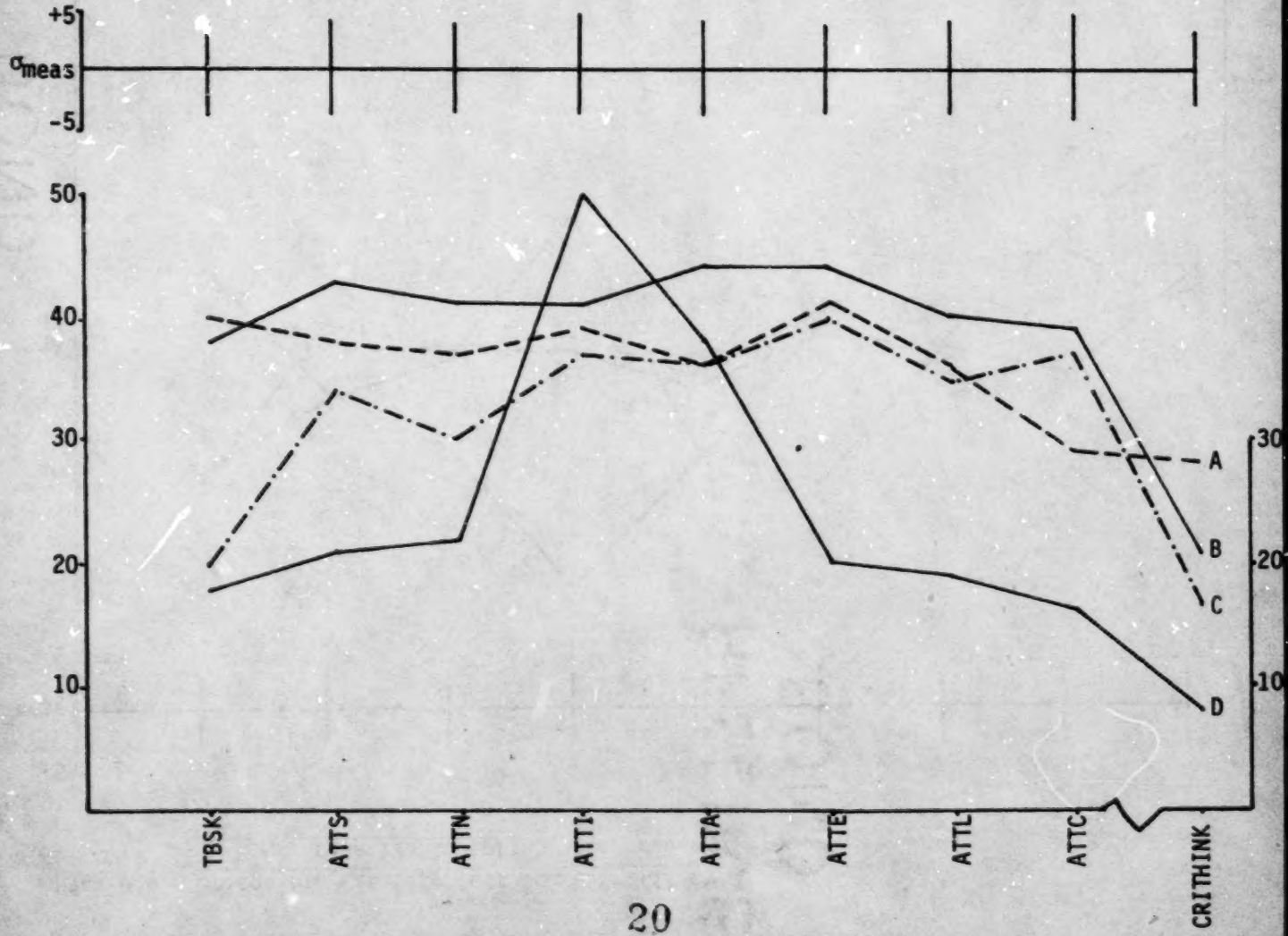
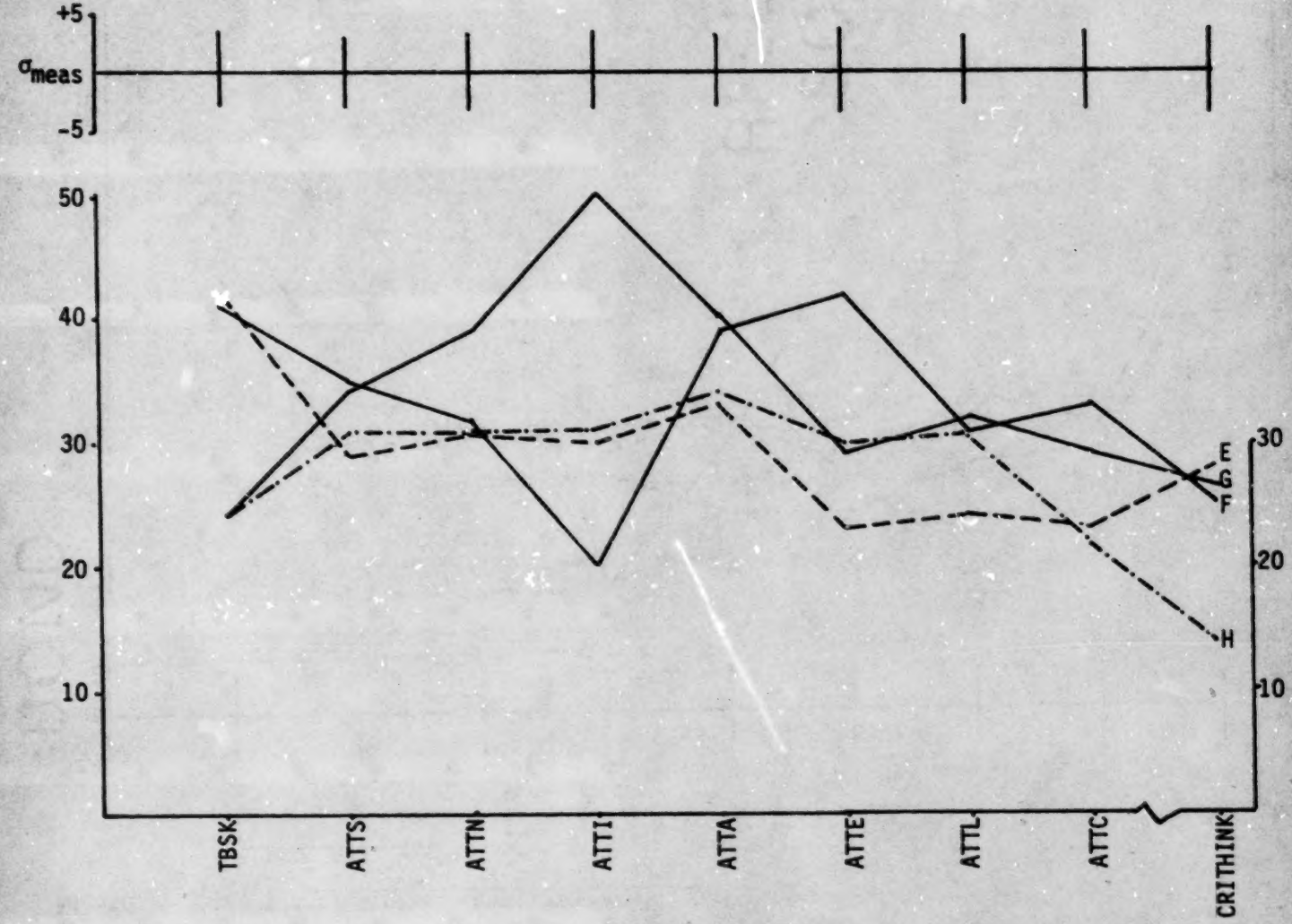


Figure 4 Scientific Literacy Test Score Profiles
Four Grade 12 Students



Conclusions and Implications

Data obtained from this study constitute an initial measure of the scientific literacy of students in years 10 and 12 in four Brisbane high schools. A number of interesting areas for further investigation have been identified. These include the disappointingly low status of scientific literacy particularly among year 12 students, some apparent differences between schools and years in relation to the intercorrelations between scores on the scales employed in the study, and possible means whereby teachers may be able to increase the level of their students' attainment in the various dimensions of scientific literacy.

While it was not the intention of the investigators to specify the relative importance of each dimension of scientific literacy in reporting students' progress, it is suggested that if teachers are serious about the scientific literacy of their students they should attempt to measure attainment in each dimension. This study describes one method of doing this for five of the seven dimensions of scientific literacy elaborated by Showalter (1974).

Appendix

TABLE A1

Mean Scores and Standard Deviations for Year 10 Students on the Nature of Science Knowledge Scale and the Science Process Inventory

INSTRUMENT	N.	MEAN	S.D.
NSKS	154	154.7	12.5
SPI	114	80.2	15.4

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